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The french way of providing the industry of insensitive missiles and munitions with appropriate high explosives and propellants

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INTRODUCTION

In the western world, explosive safety is a permanent worry of the ammunition designers, manufacturers and users. The absence of main accidents in France for many years proves the efficiency of the regulations and /or the chosen technical solutions.

Yet, the improvement of munitions performances means an increase of their potential hazards ; besides, their directions for use evolve and the threats, particularly during crisis, increase. So, it is a prime effort to keep watchful and to study all the solutions allowing to adapt oneself to the new pyrotechnical hazards.

PYROTECHNICAL HAZARDS DUE TO AMMUNITION

All the munitions (from a general point of view : for all calibers guns, missiles, rockets, bombs, mines, torpedoes...) contain energetic materials (gun propellants, high explosives, solid rocket propellants) with pyrotechnical hazards. After an accidental or a deliberate stimulus (shock, fire, bullet...), these materials are likely to decompose or to react. This reaction means that the munition produces thermal fluxes, projections, shock waves, aerial overpressures...
This reaction may on its turn, from the first munition hit, propagate to other neighbouring munitions and lead to very huge accidents. The explosion of the Ojiri store, in Pakistan, in april 1988, which deathtoll rose to several thousands, or the Forrestal (US Navy) accident in july 1967, are two examples that can be put forward. That is the reason why the safety and the survival of combat-platforms and munitions stores are factors considered more and more important by western armies.

THE SOLUTIONS

Pyrotechnical safety is a problem that has been studied for many years and which is in France very precisely and strictly regulated (safety of workers, storage, transport...)
Some technical dispositions can fix today a satisfying safety level :

- protections by materials that decrease the energy of the first stimulus,
- dividing walls that slow or stop the propagation of the accident,
- arrangement of the munitions with each other and use regulations,
- intervening devices.

But, all these solutions apply to the external environment of the munition ; technological progress of the two last decades allow now, in order to decrease risks, to choose other solutions to be applied directly to explosive materials or the other components of the munitions.

These progresses lead in the western world to the concept of "Munitions à Risques Atténués" (MURAT in french, IM for Insensitive Munitions in american, or LOVA for Low Vulnerability Ammunitions in english) or "muratisation".

THE "MURATISATION" IN FRANCE

In France, the first studies applied to the "muratisation" have been initiated in the beginning of the 80's and leaded by the Service Technique des Poudres et Explosifs (STPE), Technical Board for solid energetic materials in the DGA (General Delegation for Armament).
The DGA is the organism in the french ministry of defense in charge with :

- the development and the acquisition of ordnance that fit the needs of the french armies.
- the good health of the french industrial armament companies
  (under state control, nationalized or private)
- the development of armament exports

Within DGA, the STPE is the official board in charge with the orientation and contracting of the studies of synthesis, formulation and development of energetic substances (gun and rocket propellants, high explosives) for military use. SNPE is contracted for most of these studies but several DGA research centers are in charge with the assessment phase (GERBAM and GERPY of the Directorate of Navy Armament, ETBS of the Directorate of Army Armament, CEL of the Directorate of Missiles) and the understanding of detonics phenomena (CEG of Directorate of Research and Technical Studies, franco-german research institute ISL).

EVALUATION OF THE SENSITIVITY OF ENERGETIC MATERIALS LINKED WITH THE CONCEPT OF MURAT

If a MURAT label can be granted to a given munition and a level of immunity set for target linked with the use and the mission of this munition, it is not the same for energetic materials.

Indeed, it has been known that the reactivity of these materials when submitted to a stimulus will depend on :
- their confinement
- the masses to be considered
- the geometry of the charge

Besides, the immunity of a munition can be assessed rigorously only through scale 1 and rather important numbered tests ; these tests cost much money and can be realized only at the end of the development phase, so too late.
That is why the effort has been devoted for several years in France to the development of a set of tools allowing to predict the behaviour of such an energetic material. These are :
- the tools for the fundamental knowledge of the detonic behaviour
- the tools for the fundamental knowledge of the reaction mechanisms linked to the stimulus
- the laboratory scale tests (involving small quantities of products)
- numerical modelings to be applied to the real case of the munition
- the tests on analogues (allowing a first overview of mass and confinements effects)

1 - Fundamental knowledge of the detonic behaviour

For example, these classical tests can be put forward :
- failure dimensions of detonation (diameter, thickness, predetonation length...)
- measurements of POP PLOTS
- cylinder tests, ballistic properties

2- Fundamental knowledge of the reaction mechanism linked to the stimulus

The main mechanisms that could lead to the detonation of an energetic material are :

- the shock to detonation transition (SDT) (example of the impact of a shaped charge jet)
- the deflagration to detonation transition (DDT) (example of the bullet impact)
- the delayed shock to detonation transition (XDT) (example of a bullet impact on an energetic rocket propellant)
- the detonation after a slow heating (cook-off phenomenon)

3- The laboratory scale tests

They can check the behaviour of products and, considering elementary stimuli representative of accidental ones, rank them.
These are for example :

- the card gap tests for the phenomenon of SDT
- the dangerous friability test for DDT
- the pick-up tests or ability for delayed detonation for XDT
- the slow and fast cook off tests..

4- The numerical modelings

For the most, designed by SNPE and CEG, these computing codes allow, owing to fundamental data on the detonic behaviour of the products and after checkings with model tests, to predict the real behaviour of pyrotechnical substances at the munition scale (type of reaction and time before reaction).

Such computing codes have been developed for :

- the bullet impact
- the fragment impact
- the heatings
- the shaped charge jet
- the spigot

5- The tests on analogues

These tests, launched by the STPE several years ago, are intermediate between laboratory tests and scale 1 tests. These stimuli are the accidental ones that will be considered for the MURAT labels :

- 12,7 mm bullet impact
- heavy fragment impact (250 g ball)
- fast cook-off (fuel fire) test
- slow cook-off (3,3°C/hr)
- crush with an 8 kg bullet
- shaped-charge jet impact (ø 62 mm)
- sympathetic detonation

These stimuli can generate six reaction levels : no reaction, combustion,pressure burst, deflagration, partial detonation, detonation.

In order to take into account the mass and confinement effects, the products are assessed in analogues fitted to their operational use (the mass considered in the followings is the product mass)

- for the high explosives :

  .5 kg analogue model with a 10 mm steel confinement
  .soon, 5 kg analogue model with a 3 mm aluminum confinement
  .soon, 50 kg analogue model with a 15 mm steel confinement

- for the gun propellants :

  . 2 kg steel cartridge (Ø 90 mm)
  . 2 kg combustible case (Ø 90 mm)

- for the rocket propellants :

  . 5 kg steel model Ø 120, grain with a bore
  . soon, 15 kg steel model Ø 190

WORKS ON LOW SENSITIVE PYROTECHNICAL MATERIALS FORMULATION FOR MURAT

Owing to the methods that have been described above, the knowledge of the pyrotechnical behaviour of substances and of the reaction phenomena that occur have allowed the orientation of synthesis and formulation works towards MURAT compositions.

For example, it has been showed that :

- a good behaviour to bullets impacts requires high mechanical properties.
- a good behaviour to heatings requires the use of plastic binders
- in both cases, low sensitive molecules (NTO, TATB) should replace HMX or RDX.

The followings describe, for the 3 families of pyrotechnical products, the french main works of these last years and the improvements obtained, as far as sensitivity is concerned.

1/ Solid rocket propellants

One of the main activities of STPE is related to the research and development of solid propellants that are to be used in the future French missiles.

For several years, we have been devoting ourselves to the design of a wide variety of energetic compositions suitable for the different applications considered : tactical weapons (air to air, air to surface, surface to air, surface to surface) as well as missiles for the French nuclear deterrence force (ICBMs and SLBMs).

Studies are carried out on the following propellant families :

- cast modified double base (CMDB)
- elastomeric modified cast double base (EMCDB)
- composite propellants, including fuel-rich propellants for ram-rockets
- crosslinked composite double base (XLDB)

For the past few years, efforts have been focused on low-vulnerability propellants in order to meet the MURAT challenge.

This concerns the improvement of existing families by incorporating new additives (for example additives that lower the vulnerability of composite propellants to cook-off or to bullet impact, additives that lower the burning rates at atmospheric pressure, additives that improve cracking aging), as well as the elaboration of new families of propellants based on glycidyl azid polymer (GAP).

Fundamental studies are carried out in conjunction with formulation works with the aim to understand the different mechanisms involved when the propellant is under aggression. Important results have been obtained concerning the discovery and explanation of the so-called "bore effect" that leads to the detonation of propellant grains presenting a cylindrical bore in the bullet impact tests.

2/ <u>Gun propellants</u>

In the gun propellants field, most of the studies were devoted to :

- the study of new gun propellants with polymeric compounds filled with energetic materials, low sensitive to different stimuli and with good mechanical properties at low temperatures
- the laboratory scale characterization of these gun propellants (sensitivity tests)
- the vulnerability tests on analogues which provided the following results :

  . crush : no reaction
  . fuel fire : ordinary combustion
  . bullet impact : no or locally limited reaction

The shaped charge sensitivity test is about to be performed.

3/<u>High explosives studies</u>

The main effort has been devoted these last years to the formulation of low sensitive to accidental stimuli (fire, light or heavy fragment impact, sympathetic detonation) cast plastic-bonded explosives and to the knowledge of these products on the detonics, vulnerability and mechanical points of view.

More precisely, these compositions have been formulated :

- cast PBX (PU binder) with a high HMX loading rate (86 %) and an average particle size (200 microns) less sensitive to bullet impact than compositions with coarser HMX grain size (350 microns) (respectively octoranes 86 A and B)

- cast PBX (B 2188) for booster use (HMX/PETN/PU binder = 40/44/16) less sensitive to fire and bullet impact than its pressed PBX booster-counterparts

- cast PBX with a high NTO loading rate and an inert HTPB binder (B 2214 : 72 % NTO, 12 % HMX) or an energetic (NC, NGl) binder (B 3017 : 76 % NTO) both much less sensitive to a 250 g fragment impact or to sympathetic detonation than melt cast explosives or HMX or RDX-based cast PBX ; for instance, a 250 g fragment impact at 1500 m/s leads to detonation in a 250 kg GP bomb loaded with TNT or RDX- based cast PBX whereas it leads at 2000 m/s to an ordinary combustion with NTO-based B 2214 !

In a parallel direction, the following actions have been leaded :

- improvement of the thermal behaviour and the aging due to cracks of cast PBX with nitroglycerine-based energetic binders.
- full study of the NTO synthesis and making at the industrial scale on a continuous process (2500 kg) after having given up the TATB-based compositions studies because of their low performances.
- study of the own influence of the type of binder, the HMX and RDX grain sizes, the ammonium perchlorate and aluminum grain sizes and loading rates on the detonics and vulnerability data.
- study of the mechanical behaviour of these high explosives to high strain rates (10000 s^{-1}), to thermal shrinking after loading and study of the cracks propagation.
- boostering of low sensitive compositions
- designs of a blast test and an underwater assessment test at small scale (1 kg)

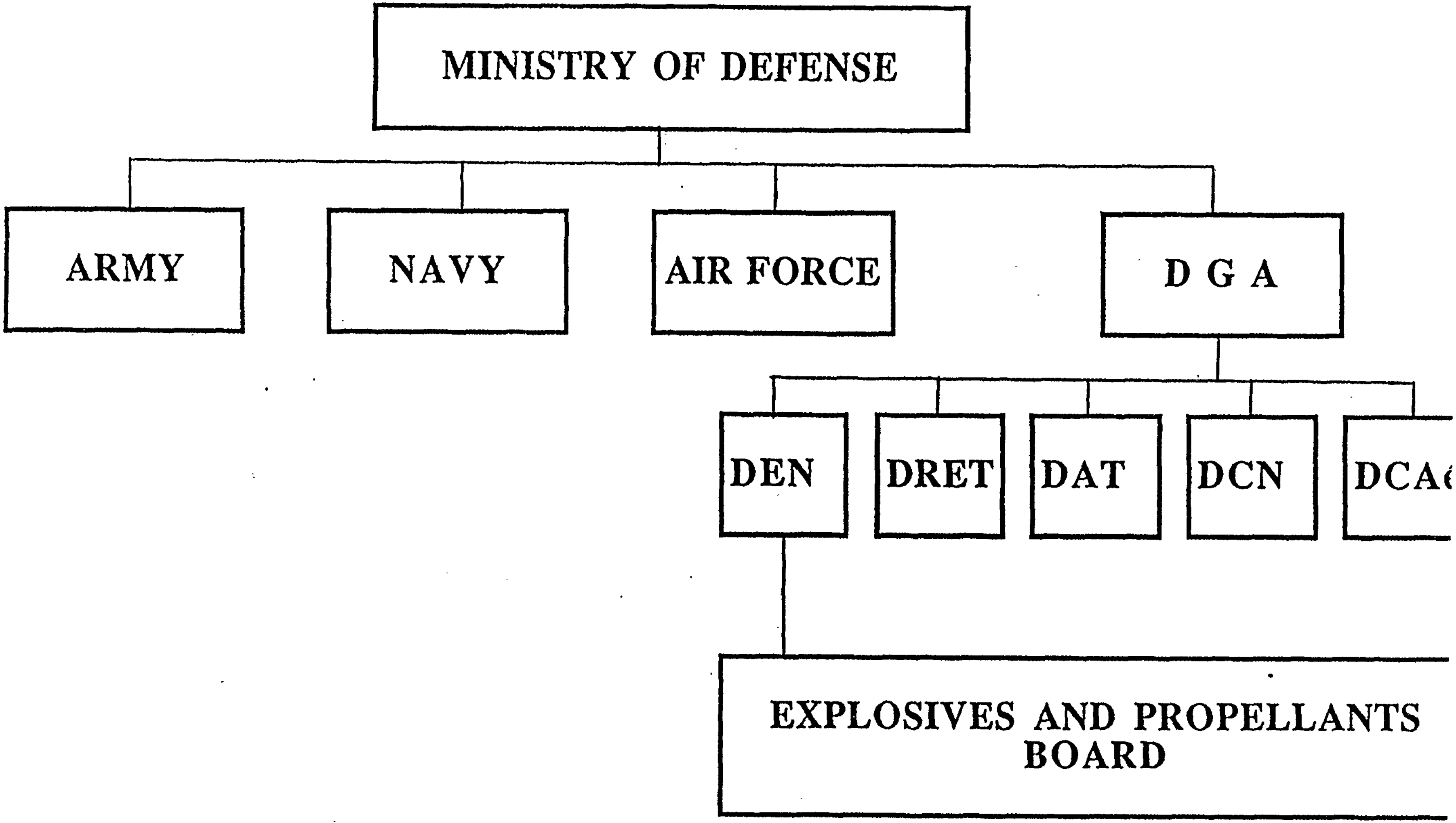
High performance pressed PBX have also been formulated for munitions like the MLRS and a theoretical study of the coating of the grains by the binder has been launched.

THE MURAT ECONOMIC BET

So, all these data allow to define a MURAT policy. According to that policy, the major economic bet must be taken into account.
Indeed, the application to MURAT munitions is not costless ; for instance, the new propellants and high explosives families will be, at least in the short term, more expensive than former ones. Therefore, the whole problem must be considered. If the fact that 90 % of the accidents involving a munition take place not during an operational phase but during "passive" phases (storage, transport...) is taken into account, the improvement expected owing to these materials (lighter protections, smaller storage areas allowing savings in sub. and understructures...) can be easily pictured. But, as for every insurance, this improvement is very difficult to assess before the accident takes place ; and everybody knows that the insurance is expensive only before the accident.

CONCLUSION

Energetic materials for MURAT are available in France today ; the first works linked to parts of munitions (warheads for example) have been completed and technical and operational studies are under way (connected with the nuclear aircraft-carrier for instance).
Owing to STPE, France leads an important research policy concerning the energetic substances to be loaded in the MURAT.
In order to know more about the french realizations, you are invited to attend the second "Journées Paul Vieille" in Paris during the 1991 autumn.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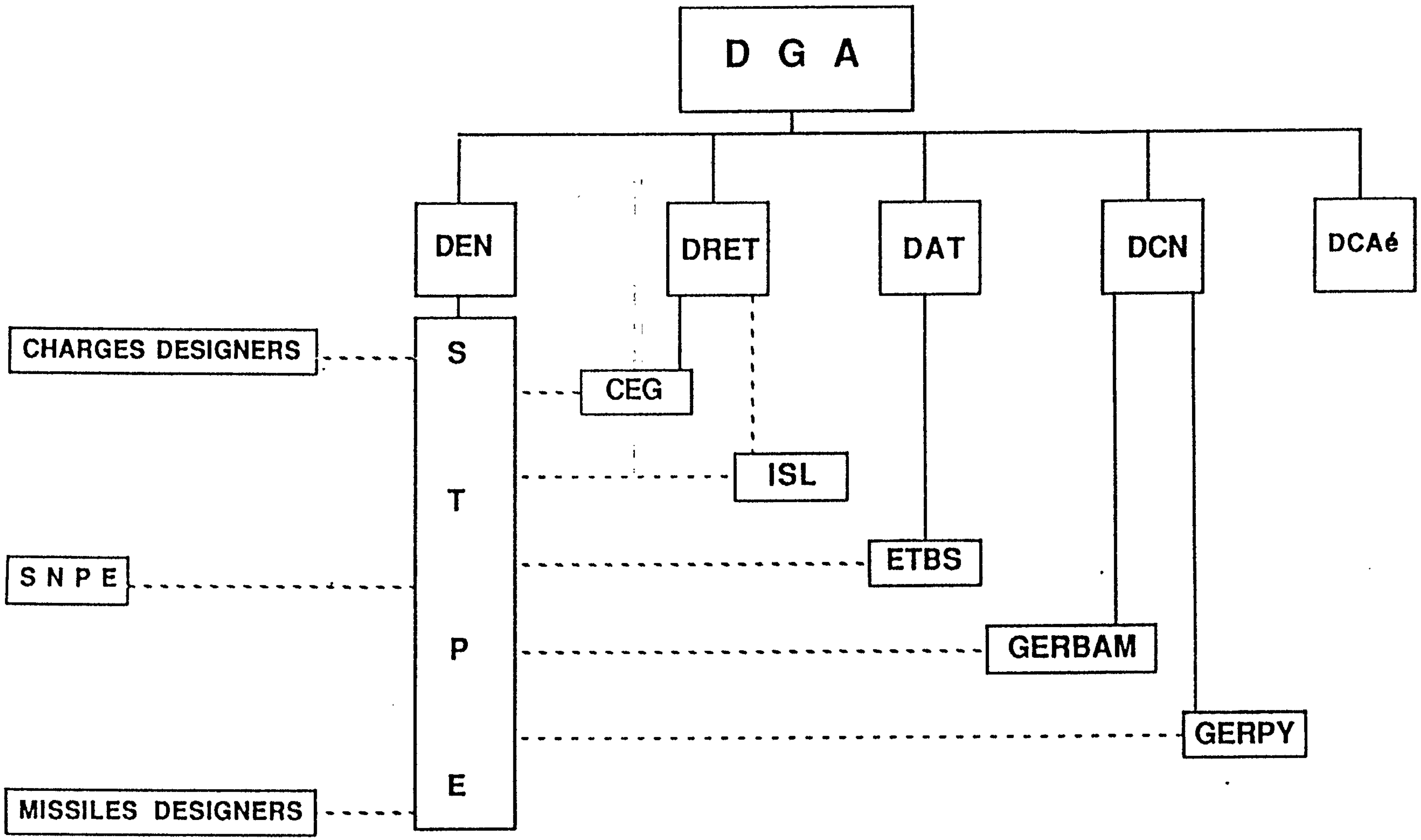
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DELEGATION GENERALE POUR L'ARMEMENT

(D G A)

* IT IS THE DEPARTMENT OF DEFENSE ORGANIZATION RESPONSIBLE FOR MANAGING ALL ARMAMENT PROGRAMS

* THEREFORE, THE DGA IS RESPONSIBLE FOR :

  - THE MANAGEMENT OF ARMAMENT PROGRAMS (ARMY - NAVY - AIR FORCE)

  - THE MONITORING OF THE ARMAMENT INDUSTRY

  - PRODUCTION AND REPAIRS OF SOME MILITARY EQUIPMENTS

  - COOPERATION AND EXPORTS FOR ARMAMENTS.

EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON HIGH EXPLOSIVES ANALOGUES.

	CRUSH TEST	FAST COOK OFF
TNT or TNT/AL	O	B
MELT CAST X	D	D
PBX (inert or energetic binder)	O	B
PRESSED PBX (with RDX or HMX)		D
PRESSED PBX (with TATB)		B

O	NO REACTION		
A	COMBUSTION	C	DEFLAGRATION
B	OVER PRESSURE BURST	D	DETONATION

EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON HIGH EXPLOSIVES ANALOGUES.

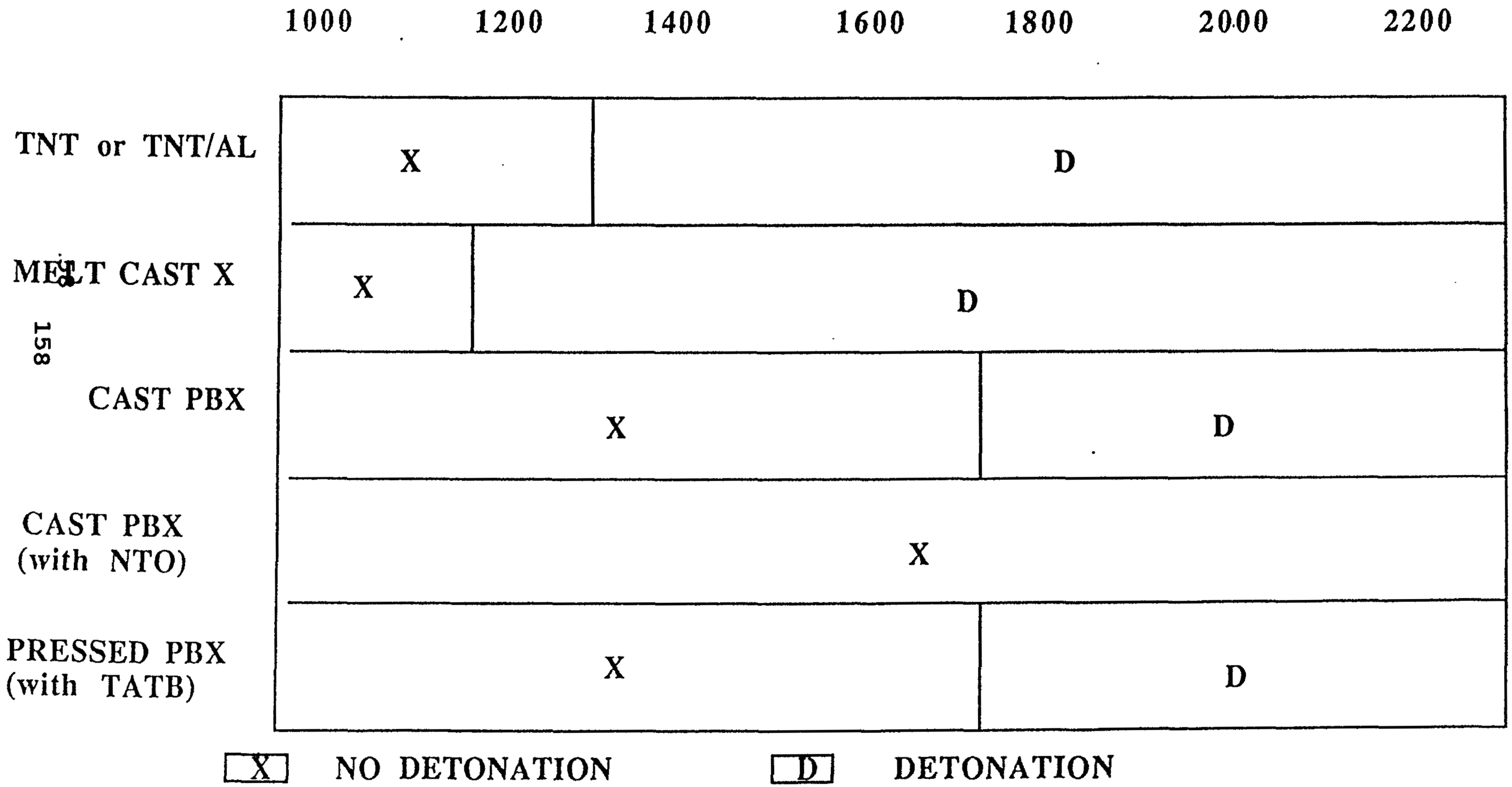
0,50 CAL. BULLET IMPACT TEST

	400 M/S	600 M/S	800 M/S	1000 M/S	1200 M/S
TNT or TNT/AL	O	B	B	B	B
MELT CAST X	D	D	D	D	D
PBX (inert or energetic binder)	O	B	B	B	B
PBX (with TATB)	O	O	A	A	A
PRESSED PBX (with RDX or HMX)	D	D	D	D	D
PRESSED PBX (with TATB)	B	B	B		

O	NO REACTION
A	COMBUSTION
B	OVER PRESSURE BURST
C	DEFLAGRATION
D	DETONATION

EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON HIGH EXPLOSIVES ANALOGUES

HEAVY FRAGMENT (250 G) IMPACT TEST



EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON GUN PROPELLANT ANALOGUES.

0,50 CAL. BULLET IMPACT TEST

	400 M/S	600 M/S	800 M/S	1000 M/S	1200 M/S
SINGLE BASE OR DOUBLE BASE G.P.	C	C	C	C	C
ENERGETIC-SMALL WEB DOUBLE BASE G.P.	C	D	D	D	D
CAST DOUBLE BASE (RDX) G.P.	A	A	A	A	B

A	NO REACTION OR COMBUSTION
B	OVER PRESSURE BURST
C	DEFLAGRATION
D	DETONATION

EG. OF TYPICAL RESULTS OBTAINED WITH TESTS ON GUN PROPELLANT ANALOGUES.

	FAST COOK OFF	SLOW COOK OFF	CRUSH
SINGLE BASE OR DOUBLE BASE G.P.	C	C	C
ENERGETIC-SMALL WEB DOUBLE BASE G.P.	D	D	D
CAST DOUBLE BASE (RDX) G.P.	B	B	A

A	NO REACTION OR COMBUSTION
B	OVER PRESSURE BURST
C	DEFLAGRATION
D	DETONATION

THE DIFFERENT ROCKET PROPELLANT FAMILIES

PROPELLANT	CONSTITUTION	ISP (EXPERIMENTAL)	APPLICATION
C M D B	NC + NG + RDX	230 s	ANTI-TANK
E M C D B	NC + NG + RDX + (PREPOLYMER)	230 s	TACTICAL
COMPOSITE	HTPB + AP HTPB + RDX or HMX CTPB or HTPB + AP +AL	240 s 235 s 245 s	ALL TACTICAL GAS GENERATORS ICBM, SLBM, BOOST MOTORS
X L C D B	POLYURETHANE + NC + NG + RDX or HMX + (AP) + (Al)	235 - 254 s	ALL
?	GAP + NA GAP + ...	236 s (THEORETICAL) 262 s (THEORETICAL)	ALL IM ALL IM + ICBM + SLBM

LOW VULNERABILITY ROCKET PROPELLANTS

FORMULATIONS

* EXISTING FAMILIES :

RESEARCH FOR NEW ADDITIVES TO REDUCE

- VULNERABILITY TO COOK-OFF
- VULNERABILITY TO IMPACT
- BURNING RATE AT ATMOSPHERIC PRESSURE
- CRACK FORMATION
- ....

* GAP/AN FAMILY

BASED ON AN INSENSITIVE PROPELLANT, THE GOAL IS TO IMPROVE PERFORMANCE

FUNDAMENTAL STUDIES

* ANALYSIS OF TRANSITION PHENOMENA : SDT, DDT, XDT

* THERMAL BEHAVIOUR TOWARDS SLOW A FAST COOK-OFF

* INVESTIGATION OF THE MECHANISMS INVOLVED IN DIFFERENT TESTS (BULLET IMPACT, ...)

GUN PROPELLANTS

- NEW FORMULATIONS

- SENSITIVITY AND VULNERABILITY TESTS

* LABORATORY SCALE
* ANALOGUES

G.P. / TESTS	SINGLE BASE	M U R A T
CRUSH	DEFLAGRATION	NO REACTION
BULLET IMPACT (.50)	DEFLAGRATION	LOCALLY LIMITED OR NO REACTION
FUEL FIRE (FCO)	"	ORDINARY COMBUSTION

COMPARISON WITH CLASSICAL COMPOSITIONS

CRITERIA / COMPOSITION	BULLET IMPACT (12,7 mm)	FIRE	HEAVY FRAGMENT IMPACT (250 g)	PERFORMANCE (ρ, D)
TNT	O	O	-	-
OCTOL 85/15	- -	- -	- -	+ +
OCTORANE 86 A	O	+	O	+
OCTORANE 86 B	+	+	O	+
B 2214	+ +	+ +	+ +	O
B 3017	+ +	+	+ +	+
B 2188 (BOOSTER)	+	+	?	+
CLASSICAL PRESSED PBX BOOSTER	- -	-	?	+

SENSITIVIY LEVEL : FROM - - (VERY SENSITIVE) TO + + (LOW SENSITIVE)

NTO CHRONOLOGY IN FRANCE

SUMMARY

1906	1st synthesis in Germany
1979 - 1980	1st synthesis at the laboratory scale at SNPE/CRB (30 g). Beginning of characterization
1981 - 1982	Scale up to 200 g : recrystallization and rest of characterization (SNPE/CRB)
1983 - 1984	First use in cast PBX
1984 - 1985	Attempts to formulate gun and rocket propellants and pressed PBX with NTO
85/06/30	SNPE patent n° F 22, 584, 066
1985	Scale-up to 20 then 50 kg (plant of Sorgues)
1985 - 1987	Comparison between TATB and NTO as desensitizers in high explosives
1987	SNPE communications at the ICT Karlsruhe and at the Peking ISPE congresses
1989	SNPE communication at the 9th symposium on detonation
1990	Communication at the ADPA congress SNPE patent on NTO-based cast PBX with energetic binders Synthesis at the industrial scale (2,5 t) in the SNPE plant of Sorgues

STPE MAIN ACTIVITIES

PROPELLANTS MATERIALS

- XLDB PROPELLANTS
- COMPOSITE PROPELLANTS
- RAMJET PROPELLANTS
- SMOKELESS PROPELLANTS
- FAST BURNING PROPELLANTS
- LOVA PROPELLANTS
- LINERS, INHIBITORS...

- MECHANICAL BEHAVIOR
- INTERNAL BALLISTICS

- NEW TACTICAL MOTOR DESIGNS
- POST BOOST SYSTEMS & GAZ GENERATORS

- PROCESSES (incl. continuous)

EXPLOSIVES

- XLDB EXPLOSIVES
- CAST PBX
- NEW INGREDIENTS
- BULK EXPLOSIVES

- MECHANICAL BEHAVIOUR
- DETONICS

- PROCESSES

GUN PROPELLANTS

- LOVA, COMPOSITE (GP)
- NEW ENERGETIC FORMULATIONS
- NEW INGREDIENTS

- STABILITY
- INTERNAL BALLISTICS

- FUTURE SYSTEMS (Careless GP)

- PROCESSES

VULNERABILITY-RAW

- SYNTHESIS
  . GAP
  . BUTACENE
  . CATOGENE
  . HTPB, ...

- VULNERABILITY :
  . METHODOLOGY
  . TESTS

- IMPACT (BULLET-FRAGMEN
- COOK-OFF (Slow-Fast)
- SYMPATHETIC DETONATIO
- SHAPED CHARGE
- ESD

+ taking account of a munition point of view

- SAFETY : - PROCESS
  - COMPATIBILITY

STPE MAIN RESEARCHES

	GUN PROPELLANTS	HIGH EXPLOSIVES	ROCKET PROPELLANTS
NEW MOLECULES	NQ GAP	TNAZ NTO GAP	GAP DPA AN
NEW FAMILIES	C A S T	P B X	•RDX LOADED XL DB •RAMJET PROPELLANTS •DPA or GAP BASED •FORMULATIONS •NON-BURNING RP at •ATM PRESSURE
PHYSICS OF MATERIALS	COARSER	GRAIN	SIZES
PROCESSES	• AIR MILLING	OF • CONTINUOUS	NITRAMINES PROCESSES
	USE OF SCREWERS	- EXTRUDERS	
		•NEW PROCESSES •HMX SYNTHESIS	
SYSTEMS APPROACHES	COMBUSTIBLE CASES	•LASER BOOSTER •MACH WAVE GENERATOR •BI-COMPOSITIONS •COMPO + "INERT" (HTPB, POROUS AL)	•COMPOSITE CASES •APPROPRIATE EXTERNAL AND BORE Ø •RAMJETS
	EXTERNAL	PROJECTING	DEVICES